



US009604070B2

(12) **United States Patent**
Sullivan et al.

(10) **Patent No.:** **US 9,604,070 B2**
(45) **Date of Patent:** **Mar. 28, 2017**

(54) **EXTERNAL DEFIBRILLATION WITH
AUTOMATIC POST-SHOCK
ANTI-TACHYCARDIA (APSAT) PACING**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 188 days.

(21) Appl. No.: **13/802,399**

(22) Filed: **Mar. 13, 2013**

(65) **Prior Publication Data**
US 2014/0100622 A1 Apr. 10, 2014

Related U.S. Application Data

(60) Provisional application No. 61/711,845, filed on Oct. 10, 2012.

(51) **Int. Cl.**
A61N 1/39 (2006.01)
A61N 1/362 (2006.01)

(52) **U.S. Cl.**
CPC *A61N 1/3962* (2013.01); *A61N 1/3621* (2013.01); *A61N 1/3625* (2013.01); *A61N 1/3925* (2013.01); *A61N 1/3987* (2013.01)

(58) **Field of Classification Search**
USPC 607/4
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,980,856 B2 * 12/2005 Sullivan A61N 1/39 607/10
2003/0060723 A1 * 3/2003 Joo A61B 5/0535 600/510
2007/0032830 A1 * 2/2007 Bowers A61N 1/39 607/5

OTHER PUBLICATIONS

Klein, Helmut U. et al., Risk stratification for implantable cardioverter defibrillator therapy: the role of the wearable cardioverter-defibrillator, *European Heart Journal*, May 31, 2013, 14 pages, European Society of Cardiology, France.
LifeVest System Model WCD 3100 Operator's Manual, 48 pages, ZOLL Lifecor Corporation, Pittsburgh, PA.
LifeVest Model 4000 Patient Manual, 108 pages, ZOLL, Pittsburgh, PA.

* cited by examiner

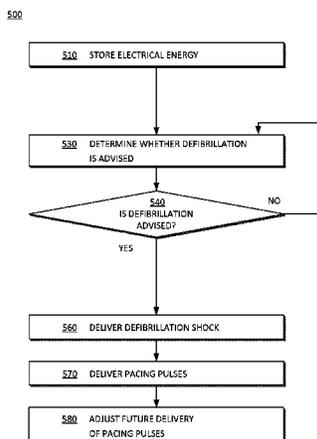
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(57) **ABSTRACT**

A medical device such as an external defibrillator delivers electrical therapy using a special pulse sequence. The special pulse sequence includes a defibrillation shock that is automatically followed by a quick succession of automatic post-shock anti-tachycardia (APSAT) pacing pulses. Because of the pacing pulses, the defibrillation shock can be of lesser energy than an equivalent defibrillation shock of a larger energy. Accordingly, the external defibrillator can be made physically smaller and weigh less, without sacrificing the therapeutic effect of a larger external defibrillator that would deliver a defibrillation shock of higher energy. As such, the defibrillator is easier to configure for transporting, handling, and even wearing.

20 Claims, 5 Drawing Sheets



METHODS

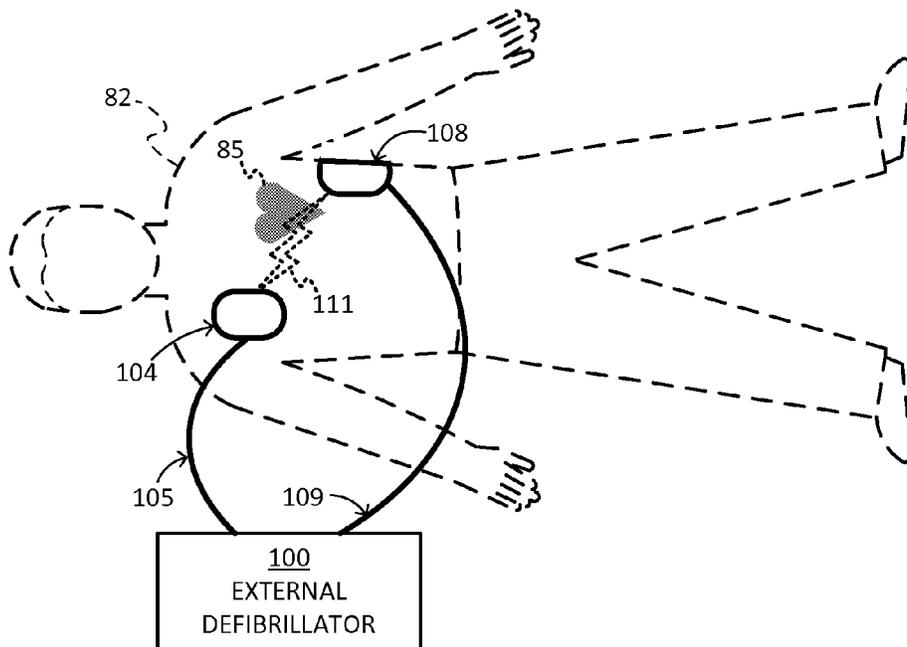


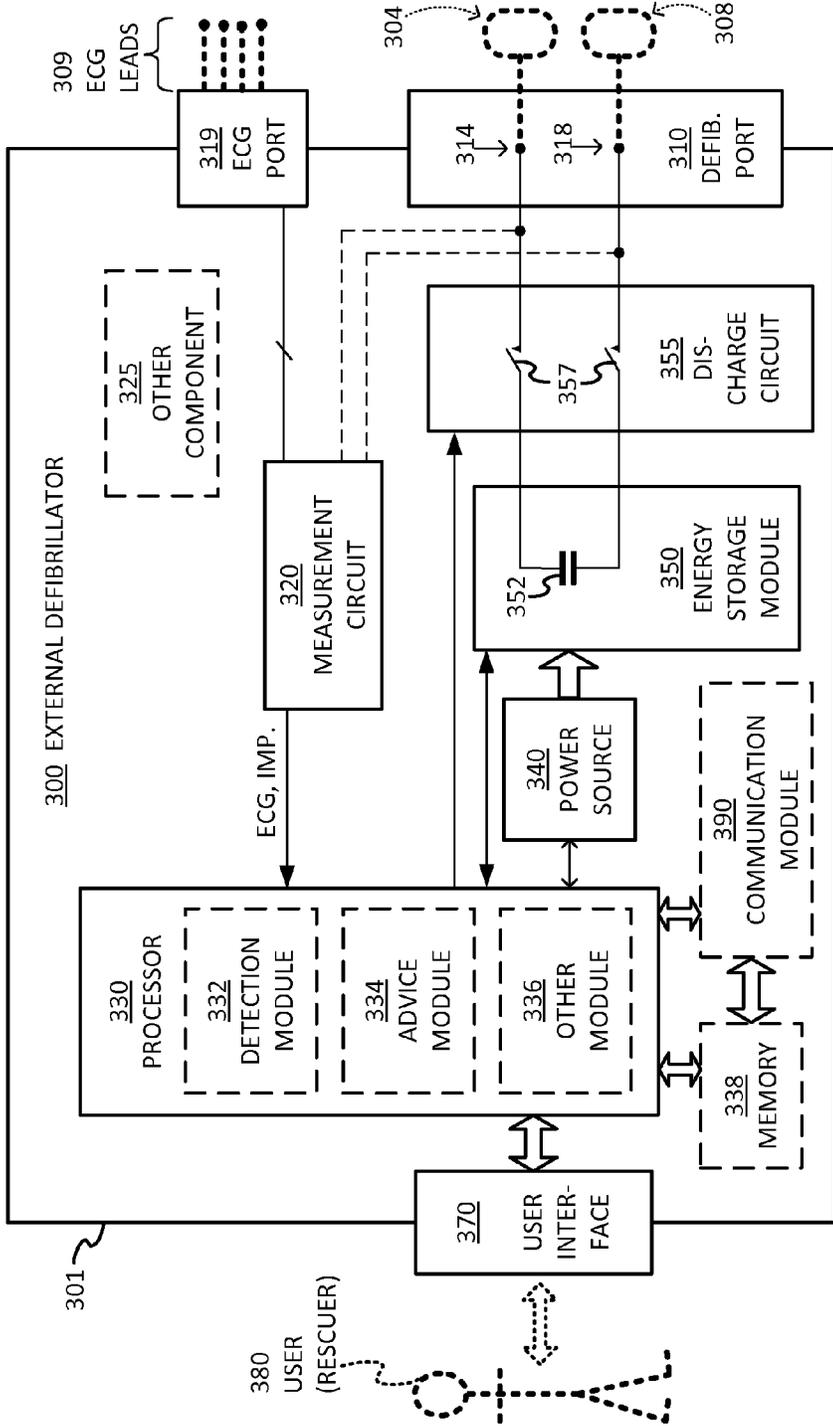
FIG. 1

DEFIBRILLATION SCENE

TYPE OF EXTERNAL DEFIBRILLATOR	INTENDED TO BE USED BY PERSONS:	
	IN THE MEDICAL PROFESSIONS	NOT IN THE MEDICAL PROFESSIONS
DEFIBRILLATOR – MONITOR	✓	
AED	✓	✓

FIG. 2

EXAMPLES OF EXTERNAL DEFIBRILLATORS



COMPONENTS OF EXTERNAL DEFIBRILLATOR

FIG. 3

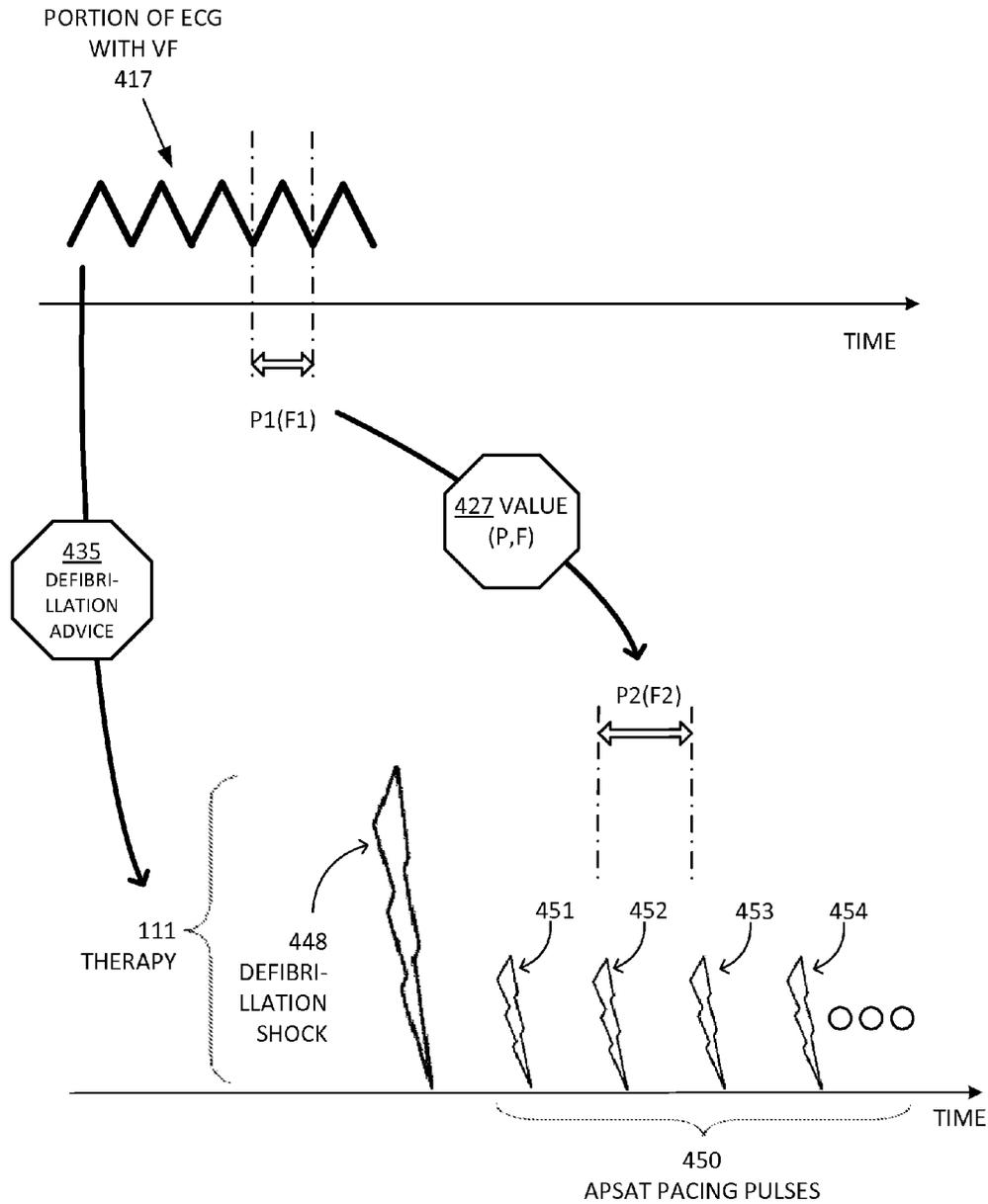
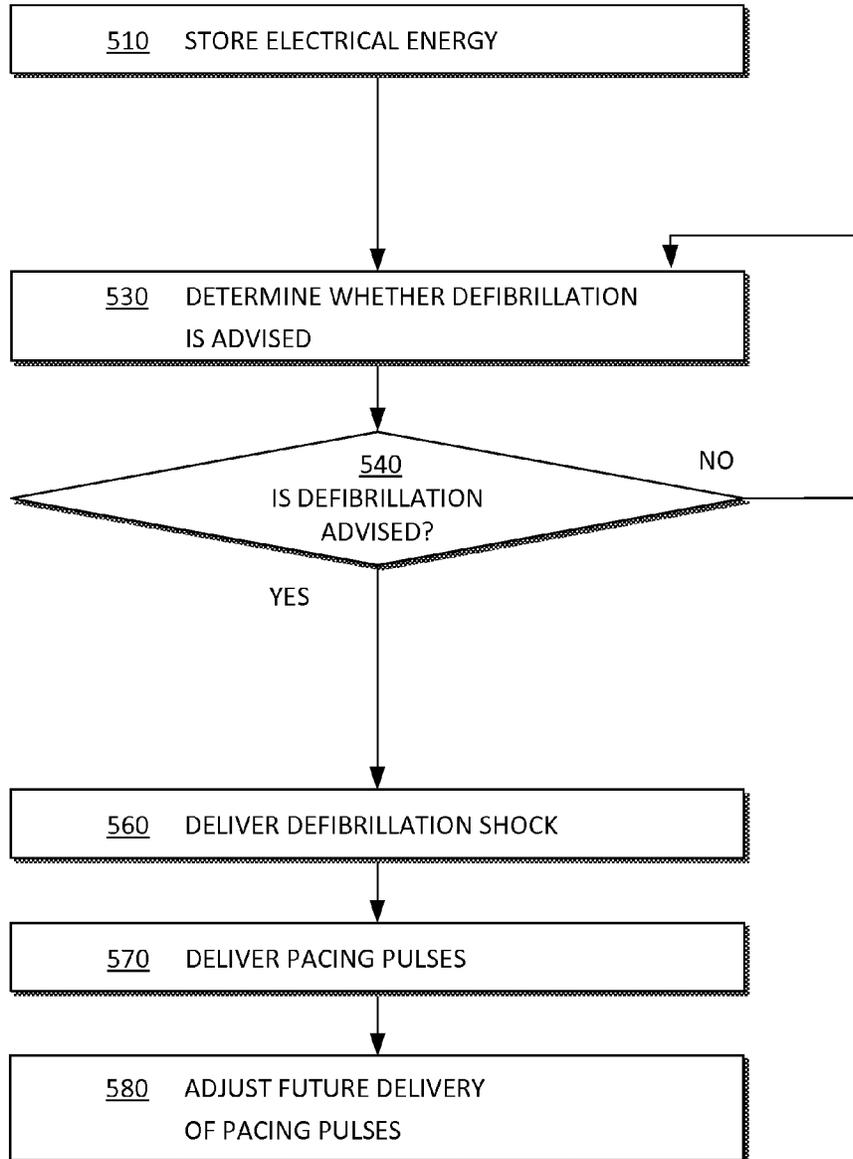


FIG. 4

EXTERNAL DEFIBRILLATION WITH
APSAT PACING

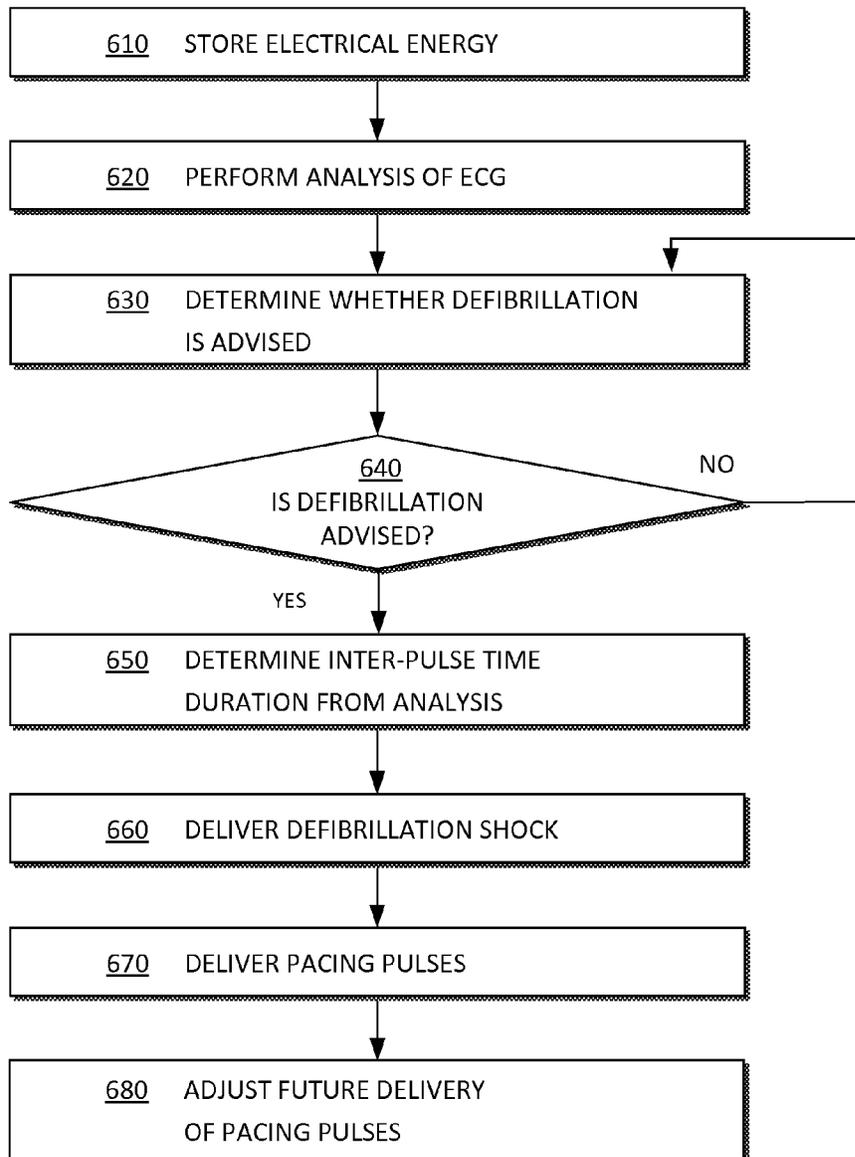
500



METHODS

FIG. 5

600



METHODS

FIG. 6

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**EXTERNAL DEFIBRILLATION WITH
AUTOMATIC POST-SHOCK
ANTI-TACHYCARDIA (APSAT) PACING**

CROSS REFERENCE TO RELATED PATENT
APPLICATIONS

This patent application claims priority from U.S. Provisional Patent Application Ser. No. 61/711,845, filed on Oct. 10, 2012, titled: "External Defibrillator with Automatic Post-Shock Anti-Tachy Pacing," the disclosure of which is hereby incorporated by reference for all purposes.

BACKGROUND

In humans, the heart beats to sustain life. In normal operation, the heart pumps blood through the various parts of the body. In particular, the various chambers of the heart contract and expand periodically, and coordinated so as to pump the blood regularly. More specifically, the right atrium sends deoxygenated blood into the right ventricle. The right ventricle pumps the blood to the lungs, where it becomes oxygenated, and from where it returns to the left atrium. The left atrium pumps the oxygenated blood to the left ventricle. The left ventricle then expels the blood, forcing it to circulate to the various parts of the body.

The heart chambers pump because of the heart's electrical control system. In particular, the sinoatrial (SA) node generates an electrical impulse, which generates further electrical signals. These further signals cause the above-described contractions of the various chambers in the heart to take place in the correct sequence. The electrical pattern created by the sinoatrial (SA) node is called a sinus rhythm.

Sometimes, however, the electrical control system of the heart malfunctions, which can cause the heart to beat irregularly, or not at all. The cardiac rhythm is then generally called an arrhythmia. Arrhythmias may be caused by electrical activity from locations in the heart other than the SA node. Some types of arrhythmia may result in inadequate blood flow, thus reducing the amount of blood pumped to the various parts of the body. Some arrhythmias may even result in a Sudden Cardiac Arrest (SCA). In a SCA, the heart fails to pump blood effectively, and, if not treated, death can occur. In fact, it is estimated that SCA results in more than 250,000 deaths per year in the United States alone. Further, a SCA may result from a condition other than an arrhythmia.

One type of arrhythmia associated with SCA is known as Ventricular Fibrillation (VF). VF is a type of malfunction where the ventricles make rapid, uncoordinated movements, instead of the normal contractions. When that happens, the heart does not pump enough blood to deliver enough oxygen to the vital organs. The person's condition will deteriorate rapidly and, if not reversed in time, they will die soon, e.g. within ten minutes.

Ventricular Fibrillation can often be reversed using a life-saving device called a defibrillator. A defibrillator, if applied properly, can administer an electrical shock to the heart. The shock may terminate the VF, thus giving the heart the opportunity to resume pumping blood. If VF is not terminated, the shock may be repeated, sometimes at escalating energies.

A challenge with defibrillation is that the electrical shock must be administered very soon after the onset of VF. There is not much time: the survival rate of persons suffering from VF decreases by about 10% for each minute the adminis-

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tration of a defibrillation shock is delayed. After about 10 minutes the rate of survival for SCA victims averages less than 2%.

The challenge of defibrillating early after the onset of VF is being met in a number of ways. To-date, for some people who are considered to be at a higher risk of VF or other heart arrhythmias, an Implantable Cardioverter Defibrillator (ICD) is implanted surgically. An ICD can monitor the person's heart, and administer an electrical shock as needed. As such, an ICD reduces the need to have the higher-risk person be monitored constantly by medical personnel.

Regardless, VF can occur unpredictably, even to a person who is not considered at a high risk. Cardiac events can be experienced by people who lack the benefit of ICD therapy. When VF occurs to a person who does not have an ICD, they collapse, because blood flow has stopped. They should receive therapy quickly.

For a VF victim without an ICD, a different type of defibrillator can be used, which is called an external defibrillator. External defibrillators have been made portable, so they can be brought to a potential VF victim quickly enough to revive them. The time from the collapse to the time a portable defibrillator is applied to the cardiac event victim is critical. Often, a physician can perceive and determine that a patient is at a risk that would qualify the patient for the invasive ICD implant. In such cases, a wearable defibrillator/monitoring device would be highly desirable.

During VF, the person's condition deteriorates, because the blood is not flowing to the brain, heart, lungs, and other organs, which can be damaged as a result. Accordingly, defibrillation must be applied quickly, to restore the blood flow. To expedite defibrillation, there have been efforts to make defibrillators ubiquitous, portable and, when needed, wearable by a prospective patient. All these efforts can be facilitated by making an external defibrillator smaller and weigh less. A persisting need exists for a smaller, lighter, and more portable defibrillator without compromising therapy and/or monitoring efficacy.

BRIEF SUMMARY

The present description gives instances of medical devices, processors, and methods, the use of which may help overcome problems and limitations of the prior art.

In one embodiment, an external defibrillator delivers electrical therapy using a special pulse sequence. The special pulse sequence includes a defibrillation shock that is automatically followed by a quick succession of automatic post-shock anti-tachycardia (APSAT) pacing pulses. Because of the pacing pulses, the defibrillation shock can be of lesser energy than an equivalent defibrillation shock of a higher energy. Accordingly, an external defibrillator can be made according to embodiments of the invention physically smaller and weigh less, without sacrificing the therapeutic effect of a larger external defibrillator that would deliver a higher energy defibrillation shock. As such, a defibrillator made according to embodiments of the invention is easier to configure for transporting, handling, and, when desirable, wearing.

These and other features and advantages of this description will become more readily apparent from the following Detailed Description, which proceeds with reference to the drawings, in which:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagram of a scene where an external defibrillator is used to save the life of a person according to embodiments.

FIG. 2 is a table listing examples of types of the external defibrillator shown in FIG. 1, and who they might be used by.

FIG. 3 is a diagram showing components of an external defibrillator, such as the one shown in FIG. 1, which is made according to embodiments.

FIG. 4 is a combination of timing diagrams for illustrating the timing of a pulse sequence according to embodiments.

FIG. 5 is a flowchart for illustrating methods according to embodiments.

FIG. 6 is a flowchart for illustrating additional methods according to embodiments.

DETAILED DESCRIPTION

As has been mentioned, the present description is about external defibrillators, processors, and methods of delivering electrical therapy using a special pulse sequence. Embodiments are now described in more detail.

Defibrillation Scene

FIG. 1 is a diagram of a defibrillation scene. A portable external defibrillator **100** is being applied to a person **82**. Person **82** could be experiencing a condition in their heart **85**, which could be Ventricular Fibrillation (VF) or a different arrhythmia. The scene of FIG. 1 could be in a hospital, where person **82** is a patient, or in some other location where an SCA victim is unconscious and then turned to be on their back. Alternatively, person **82** could be someone who is wearing defibrillator **100**.

Defibrillator **100** is usually provided with at least two defibrillation electrodes **104**, **108**, which are sometimes called just electrodes **104**, **108**. Electrodes **104**, **108** are coupled with external defibrillator **100** via respective electrode leads **105**, **109**. A rescuer (not shown) has attached electrodes **104**, **108** to the skin of person **82**. Alternatively, if defibrillator **100** is wearable, electrodes **104**, **108** have been applied to the skin before the event, or automatically.

Defibrillator **100** is configured to administer electrical therapy **111** to person **82**. In other words, defibrillator **100** can cause, via electrodes **104**, **108**, electrical energy to go through the body of person **82**, in an attempt to affect heart **85**. Therapy **111** can include a brief, strong defibrillation pulse, which is also known as a defibrillation shock, in an attempt to restart heart **85** so as to save the life of person **82**.

Defibrillator **100** can be one of different types, each with different sets of features and capabilities. The set of capabilities of defibrillator **100** is determined by planning who would use it, and what training they would be likely to have. Examples are now described.

Types of External Defibrillators

FIG. 2 is a table listing examples of types of external defibrillators, and who they are primarily intended to be used by. One of defibrillator **100** is generally called a defibrillator-monitor, because it is typically formed as a single unit in combination with a patient monitor. A defibrillator-monitor is sometimes called monitor-defibrillator. A defibrillator-monitor is intended to be used by persons in the medical professions, such as doctors, nurses, paramedics, emergency medical technicians, etc. Such a defibrillator-monitor is typically intended to be used in a pre-hospital or hospital scenario.

As a defibrillator, the device can be one of different varieties, or even versatile enough to be able to switch among different modes that individually correspond to the varieties. One variety is that of an automated defibrillator, which can determine whether a shock is needed and, if so, charge to a predetermined energy level and instruct the user

to administer the shock. Another variety is that of a manual defibrillator, where the user determines the need and controls administering of the shock.

As a patient monitor, the device has features additional to what is minimally needed for mere operation as a defibrillator. These features can be for monitoring physiological indicators and other data of a person in an emergency scenario. These physiological indicators and other data are typically monitored as signals. For example, these signals can include a person's full ECG (electrocardiogram) signals, or impedance between two electrodes. Additionally, these signals can be about the person's temperature, non-invasive blood pressure (NIBP), arterial oxygen saturation/pulse oximetry (SpO₂), the concentration or partial pressure of carbon dioxide in the respiratory gases, which is also known as capnography, and so on. These signals can be further stored and/or transmitted as patient data.

Another type of external defibrillator **100** is generally called an AED, which stands for "Automated External Defibrillator". An AED typically makes the shock/no shock determination by itself, automatically. Indeed, it can sense enough physiological conditions of the person **82** via only the shown defibrillation electrodes **104**, **108** of FIG. 1. In its present embodiments, an AED can either administer the shock automatically, or instruct the user to do so, e.g. by pushing a button. Being of a simpler construction, an AED typically costs much less than a defibrillator-monitor. As such, it makes sense for a hospital, for example, to, as a back-up, deploy AEDs at its various floors, in case the more expensive defibrillator-monitor is more critically being deployed at an Intensive Care Unit, and so on.

AEDs can also be used by people who are not in the medical professions. More particularly, an AED can be used by many professional first responders, such as policemen, firemen, etc. Even a person with only first-aid training can use one. And AEDs increasingly can supply instructions to whoever is using them.

AEDs are thus particularly useful, because it is so critical to respond quickly, when a person suffers from VF. Indeed, the people who will first reach the VF sufferer may not be in the medical professions.

Increasing awareness has resulted in AEDs being deployed in public or semi-public spaces, so that even a member of the public can use one, if they have obtained first aid and CPR/AED training on their own initiative. This way, defibrillation can be administered soon enough after the onset of VF, to hopefully be effective in rescuing the person.

With either of the described-above types of defibrillator, a cardiac victim must depend on prompt responsiveness of a bystander/rescuer. Another type of such a defibrillator is a wearable defibrillator, which is configured so that it can be worn by the patient for long time durations. These time durations are preferably days and weeks, and in any event at least one hour. Wearable defibrillator is capable of automatic autonomous response to a cardiac event. The delay from the onset of the event to the administration of therapy/care is in this case dramatically reduced. There are additional types of external defibrillators, which are not listed in FIG. 2. For example, a hybrid defibrillator can have aspects of an AED, and also of a defibrillator-monitor. A usual such aspect is additional ECG monitoring capability. Other types of defibrillators are possible, as would be apparent to a person skilled in the art.

Example External Defibrillator

FIG. 3 is a diagram showing components of an example external defibrillator **300** made according to embodiments. These components can be, for example, in external defibril-

lator **100** of FIG. 1. Plus, these components of FIG. 3 can be provided in a housing **301**, which is also known as casing **301** or may work as a system **301** comprised of modular components interacting with one another.

External defibrillator **300** is intended for use by a user **380**, who would be the rescuer. Defibrillator **300** typically includes a defibrillation port **310**, such as a socket in housing **301**. Defibrillation port **310** includes nodes **314**, **318**. Defibrillation electrodes **304**, **308**, which can be similar to electrodes **104**, **108**, can be plugged in defibrillation port **310**, so as to make electrical contact with nodes **314**, **318**, respectively. It is also possible that electrodes can be connected continuously to defibrillation port **310**, etc. Either way, defibrillation port **310** can be used for guiding via electrodes to person **82** an electrical charge that has been stored in defibrillator **300**, as will be seen later in this document.

If defibrillator **300** is actually a defibrillator-monitor, as was described with reference to FIG. 2, then it will typically also have an ECG port **319** in housing **301**, for plugging in ECG leads **309**. ECG leads **309** can help sense an ECG signal, e.g. a 12-lead signal, or from a different number of leads. Moreover, a defibrillator-monitor could have additional ports (not shown), and another component **325** for the above described additional features, such as patient signals.

Defibrillator **300** also includes a measurement circuit **320**. Measurement circuit **320** receives physiological signals from ECG port **319**, and also from other ports, if provided. These physiological signals are sensed, and information about them is rendered by circuit **320** as data, or other signals, etc.

If defibrillator **300** is actually an AED, it may lack ECG port **319**. Measurement circuit **320** can obtain physiological signals through nodes **314**, **318** instead, when defibrillation electrodes **304**, **308** are attached to person **82**. In these cases, a person's ECG signal can be sensed as a voltage difference between electrodes **304**, **308**. Plus, impedance between electrodes **304**, **308** can be sensed for detecting, among other things, whether these electrodes **304**, **308** have been inadvertently disconnected from the person.

Defibrillator **300** also includes a processor **330**. Processor **330** is an article that may be implemented in any number of ways. Such ways include, by way of example and not of limitation, digital and/or analog processors such as microprocessors and digital-signal processors (DSPs); controllers such as microcontrollers; software running in a machine or a chip; programmable circuits such as Field Programmable Gate Arrays (FPGAs), Field-Programmable Analog Arrays (FPAAAs), Programmable Logic Devices (PLDs), Application Specific Integrated Circuits (ASICs), any combination of one or more of these, and so on.

Processor **330** can be considered to have a number of modules. One such module can be a detection module **332**, which senses outputs of measurement circuit **320**. Detection module **332** can include a VF detector. Thus, the person's sensed ECG can be used to determine whether the person is experiencing VF.

Another such module in processor **330** can be an advice module **334**, which arrives at advice based on outputs of detection module **332**. Advice module **334** can include a Shock Advisory Algorithm, implement decision rules, and so on. The advice can be to shock, to not shock, to administer other forms of therapy, and so on. If the advice is to shock, some external defibrillator embodiments merely report that to the user, and prompt them to do it. Other embodiments further execute the advice, by administering

the shock. If the advice is to administer CPR, defibrillator **300** may further issue prompts for it, and so on.

Processor **330** can include additional modules, such as module **336**, for other functions. In addition, if other component **325** is indeed provided, it may be operated by or included in processor **330**, in whole or in part, etc.

Defibrillator **300** optionally further includes a memory **338**, which can work together with processor **330**. Memory **338** may be implemented in any number of ways. Such ways include, by way of example and not of limitation, nonvolatile memories (NVM), read-only memories (ROM), random access memories (RAM), any combination of these, and so on. Memory **338**, if provided, can include programs for processor **330**, and so on. The programs can be operational for the inherent needs of processor **330**, and can also include protocols and ways that decisions can be made by advice module **334**. In addition, memory **338** can store prompts for user **380**, acquired or entered data about patient **82**, etc.

Defibrillator **300** may also include a power source **340**. To enable portability of defibrillator **300**, power source **340** typically includes a battery. Such a battery is typically implemented as a battery pack, which can be rechargeable or not. Sometimes, a combination is used, of rechargeable and non-rechargeable battery packs. Other embodiments of power source **340** can include AC power override, for where AC power will be available, and so on. In some embodiments, power source **340** is controlled by processor **330**.

Defibrillator **300** additionally includes an energy storage module **350**. Module **350** is where some electrical energy can be stored, when it is being prepared for sudden discharge to administer a one or more electrical discharges, as will be described later in this document. Module **350** can be charged from power source **340** to the right amount of energy, as controlled by processor **330**. In typical implementations, module **350** includes one or more capacitors **352**, and so on. Energy storage module **350** typically becomes recharged, after it delivers energy. Opportune times for such recharging are after delivering the defibrillation shock **448** described below, whether before, in-between, or after the pacing pulses that follow. More aggressive recharging may be needed depending on the desired ATP pulse level and the patient's bulk impedance.

Defibrillator **300** moreover includes a discharge circuit **355**. Circuit **355** can be controlled to permit the energy stored in module **350** to be discharged to nodes **314**, **318**, and thus also to defibrillation electrodes **304**, **308**. Circuit **355** can include one or more switches **357**. Those can be made in a number of ways, such as by an H-bridge, and so on.

Defibrillator **300** further includes a user interface **370** for user **380**. User interface **370** can be made in any number of ways. For example, interface **370** may include a screen, to display what is detected and measured, provide visual feedback to the rescuer about their resuscitation attempts, and so on. Interface **370** may also be able to issue audible prompts, such as by having a speaker for voice prompts, etc. Interface **370** may additionally include various controls, such as pushbuttons, keyboards, touchscreens, and so on. In addition, discharge circuit **355** can be controlled by processor **330**, or directly by user **380** via user interface **370**, and so on.

Defibrillator **300** can optionally include other components. For example, a communication module **390** may be provided for communicating with other machines. Such communication can be performed wirelessly, or via wire, or by infrared communication, and so on. This way, data can be communicated, such as patient data, incident information, therapy attempted, CPR performance, and so on.

As mentioned above, defibrillator **300** is capable of delivering therapy using a special pulse sequence. More particularly, processor **330** may determine whether defibrillation is advised for the patient, for example by using advice module **334**. If defibrillation is indeed advised, processor **330** may control delivery of the energy stored in energy storage module **350**. The therapy is in the form of a special pulse sequence, as is now described in more detail.

Example Timing Diagrams

FIG. 4 is a combination of example timing diagrams for illustrating the timing of a pulse sequence according to embodiments. Therapy **111** is shown along a time axis, in terms of icons that represent delivery of energy to the patient as therapy. It will be understood that, in some embodiments, the energy of therapy **111** is delivered automatically, in response to determining that defibrillation is advised for the patient. In other embodiments, the energy is delivered responsive to a user operating the user interface **370**; in those embodiments, the user would be informed that defibrillation is advised, or to activate a control, or both. In some embodiments, the energy delivered as therapy is delivered in different portions. Often a first portion is a defibrillation shock, and often a second portion is one or more pacing pulses, as described in more detail below.

Therapy **111** includes energy delivered as a defibrillation shock **448**. Defibrillation shock **448** can be delivered in any way known in the art. For example, shock **448** could be a monophasic shock, a biphasic shock, or other multiphasic shock. Shock **448** could be delivered by only two electrodes, or it could be a multi-vector shock, such as from multiple electrodes or segmented electrodes with different active segments.

Defibrillation shock **448** is clearly distinguishable from, say, pacing pulses. For example, in many embodiments, defibrillation shock **448** has energy of at least 50 Joules (J) for an adult. The defibrillation energy can be smaller, if the patient is a child or an infant.

Therapy **111** also includes energy delivered as a group **450** of APSAT pacing pulses **451**, **452**, **453**, **454**, . . . , shortly after defibrillation shock **448**. Pulse **451** is also called a lead pacing pulse **451**. The pacing pulses of group **450** are clearly distinguishable from a defibrillation pulse—for example they have energy of less than 5 J, or often less than 3 J. For example, a 200 mA pacing pulse, 40 ms long, into a 100 ohm load, delivers ~0.16 J; and into a 2K ohm load, 3.2 J.

For purposes of this document, “APSAT” stands for “Automatic Post-Shock Anti-Tachycardia”, to connote the pulses of group **450**. In some embodiments, the pulses of group **450** are automatic, in that lead pacing pulse **451** is delivered without analyzing an ECG of the patient in a time interval between when defibrillation shock **448** has been delivered and lead pacing pulse **451** has been delivered, and/or without making any other preparation or needing to receive any input for lead pacing pulse **451** after defibrillation shock **448** has been delivered. The automatic aspect can be extended to others of the pacing pulses, such as **452**, **453**, **454**, etc.; in other words, two or more of the pacing pulses of group **450** can be delivered as part of a single prepared stack that includes shock **448**, without analyzing an ECG of the patient while the stack is being delivered. An advantage is that there will be no need, in some embodiments, for a separate set of electrodes to input the ECG.

In some embodiments, lead pacing pulse **451** occurs within five seconds after defibrillation shock **448** has been delivered. Often the time is shorter than five seconds—in fact the whole therapy **111** may be completed within less than five seconds. An advantage is that there will be no need

to assess whether the patient is conscious and, if so, to sedate them. In fact, VF patients tend not achieve consciousness very quickly after defibrillation shock **448**. Accordingly, there is no need to sedate the patient, and the pacing pulses **451**, . . . can be delivered at a level known to capture (e.g. 200 mA) without regard for pain.

In some embodiments, processor **330** is configured to determine whether defibrillation is advised for the patient by performing an analysis of an ECG of the patient. For example, the ECG may indicate that the patient has VF or Ventricular Tachycardia (“VT”). In some of these embodiments, the energy of therapy **111** is ultimately delivered via electrodes, and the ECG is received from the patient via the same electrodes. An example is now described.

In FIG. 4, a portion **417** of an ECG waveform is shown against a time axis. Portion **417** has VF, which generates defibrillation advice **435** that therapy **111** is advised.

In addition, an inter-pulse time duration is determined from the analysis of the ECG. The inter-pulse time duration can be advantageously determined by processor **330**, although that is not necessary for practicing embodiments of the invention.

The inter-pulse time duration can be used for the spacing of the pacing pulses in group **450**. In one embodiment, two successive ones of the pacing pulses can have that spacing between them. For example, in FIG. 4, pacing pulses **452**, **453** are successive, and pacing pulse **453** is delivered the inter-pulse time duration P2 after pacing pulse **452**.

The inter-pulse time duration P2 may be known also by its inverse, frequency F2. In some embodiments, the analysis of the ECG reveals ventricular fibrillation having a certain VF frequency F1, which corresponds to a period P1. In some embodiments, the inter-pulse time duration P2 is determined from the certain VF frequency F1. In some of those embodiments, the inter-pulse time duration P2 is determined so that it is within a factor of two of period P1. In some instances, the inter-pulse time duration P2 is determined so that it is substantially equal to period P1. The analysis generates a value **427** from P1, or F1, which is passed for generating the value of inter-pulse time duration P2.

VF frequency F2 can be measured in a number of ways. For example there can be counting of how frequently a threshold is crossed. Or a version of a Fourier transform can be performed, such as a Fast Fourier Transform (FFT). In some instances, the peak VF frequency can be estimated. To limit the computational power required to find the peak VF frequency, the FFT could be performed on a relatively short segment of data, perhaps only one or two seconds, and the FFT butterflies would only need to be calculated for frequencies in the normal VF range, which is about 5-10 Hz.

In FIG. 4, pacing pulses **451**, . . . are shown as having the same spacing among them, which is the pacing rate. A good rate would be 300 bpm (beats per minute), for a VF with an average frequency of 5 Hz.

The above embodiments are not limiting for practicing embodiments of the invention. For example, the spacing of pacing pulses **451**, . . . could vary. One variation is for the spacing to be a ramp—pacing could start at a relatively slow rate, and increase in an effort to achieve capture. In yet other embodiments, the spacing of these pacing pulses can be independent of the VF rate.

Further, while only four pacing pulses **451**, **452**, **453**, **454** are shown, embodiments of the invention could be practiced with fewer, or more. Ten pulses may be a good value to achieve overdrive capture. As to a maximum number of pacing pulses, at some point it may be unhealthy for the patient to be paced at such a high rate for a long time, but

if such pacing went on for only a few seconds there is probably no harm. For example, such pacing for, say 5 seconds, could represent as many as 500 pacing pulses—way more than necessary, but probably still no harm to the patient.

If the therapy fails to stop the fibrillation, it may be beneficial to try a different therapy. If defibrillation shock **448** was already delivered at the maximum energy available, then changing the pacing portion **450** of therapy **111** may be the only viable alternative. This is particularly true if multiple shocks have failed—why not try something else? The pacing therapy can be changed by varying the pacing rate, and possibly the number of pacing pulses, also known as the pulse train length. For example, there could be no pulses the first time; if there is failure, the pulse train length could increase in the next try, and then again after another failure. Moreover, the pulse train magnitude could be varied depending on the patient impedance, selected defibrillation energy setting, and previous shock failure. It is also possible that switching to a defibrillation shock alone may prove beneficial as a backup.

In addition, all of what is written in this document about treating VF can also be used for treating other cardiac arrhythmias, such as shockable Ventricular Tachycardia (“VT”). Such could be performed with a synchronized cardio-version shock, followed by the same sequence of APSAT pulses.

The anti-tachy pacing pulses could be delivered from the same capacitor that stored the defibrillator energy, or could be delivered from another power source. If the defibrillator capacitor is used for pacing, the capacitor could be either pre-charged with enough energy for both defibrillation and pacing, or it could be recharged during the pacing process. The defibrillator discharge circuit **355**, if implemented as an H-bridge, could be used as part of the pacing current path or the current source could be separate.

In some embodiments, measurement circuit **320** measures an impedance of the patient, while defibrillation shock **448** is being delivered. In such embodiments, capacitor **352** can be charged for delivering the additional pacing pulse to a value determined from the measured impedance.

Indeed, another advantage to this new external therapy is that the patient impedance value that is measured during defibrillation shock **448** may be utilized during pacing. To-date, defibrillators must charge the capacitor to a relatively high voltage, in order to deliver the desired current to the highest possible impedance that might be encountered. Pacing impedances can vary from 10 s of Ohms to ~2000 ohms, requiring a charge voltage of 300-400V in order to be able to reliably deliver 200 mA. With this new therapy, the patient impedance will be known before the pacing. Accordingly, capacitor **352** could be charged only as high as is necessary for this particular patient. Since most patients have a post-shock impedance of 200 ohms or less, 200 mA could be delivered with the capacitor being charged to a voltage of only about 40V. This low voltage requirement allows the pacing circuitry to be physically smaller, have lower cost, and consume less power than conventional external pacing circuitry.

Knowing the patient impedance also allows the circuit topology to be simplified. Conventional pacing circuitry requires a current source output to deliver the desired amount of current. This usually requires a method of delivering current, a method of sensing the amount of current flow, and feedback to control the current to the desired level. In accordance with embodiments of the invention, the APSAT pacing pulses may be delivered with a simpler

arrangement. Because the patient impedance is known before the APSAT pacing pulses start, the current may be controlled simply by charging capacitor **352** to the desired voltage. For example, if it were desired to deliver 200 mA to an 80 ohm patient, the capacitor would be charged to 16V.

There are several ways in which defibrillator **300** can be designed according to embodiments of the invention. One way is to use the voltage remaining from defibrillation shock **448** for some or all the group **450** of pacing pulses. This may avoid or reduce the need to recharge before pacing. While a conventional defibrillator may choose to discharge the remaining capacitor voltage after a defibrillation shock (such as for safety reasons), a defibrillator delivering this new therapy may choose to retain that voltage for pacing, and perhaps discharge after the pacing.

The functions of this description may be implemented by one or more devices that include logic circuitry. The device performs functions and/or methods as are described in this document. The logic circuitry may include a processor that may be programmable for a general purpose, or dedicated, such as microcontroller, a microprocessor, a Digital Signal Processor (DSP), etc. For example, the device may be a digital computer like device, such as a general-purpose computer selectively activated or reconfigured by a computer program stored in the computer. Alternately, the device may be implemented by an Application Specific Integrated Circuit (ASIC), etc.

Moreover, methods are described below. The methods and algorithms presented herein are not necessarily inherently associated with any particular computer or other apparatus. Rather, various general-purpose machines may be used with programs in accordance with the teachings herein, or it may prove more convenient to construct more specialized apparatus to perform the required method steps. The required structure for a variety of these machines will become apparent from this description.

In all cases there should be borne in mind the distinction between methods in this description, and the method of operating a computing machine. This description relates both to methods in general, and also to steps for operating a computer and for processing electrical or other physical signals to generate other desired physical signals.

Programs are additionally included in this description, as are methods of operation of the programs. A program is generally defined as a group of steps leading to a desired result, due to their nature and their sequence. A program is usually advantageously implemented as a program for a computing machine, such as a general-purpose computer, a special purpose computer, a microprocessor, etc.

Storage media are additionally included in this description. Such media, individually or in combination with others, have stored thereon instructions of a program made according to embodiments of the invention. A storage medium according to embodiments of the invention is a computer-readable medium, such as a memory, and is read by the computing machine mentioned above.

Performing the steps or instructions of a program requires physical manipulations of physical quantities. Usually, though not necessarily, these quantities may be transferred, combined, compared, and otherwise manipulated or processed according to the instructions, and they may also be stored in a computer-readable medium. These quantities include, for example electrical, magnetic, and electromagnetic signals, and also states of matter that can be queried by such signals. It is convenient at times, principally for reasons of common usage, to refer to these quantities as bits, data bits, samples, values, symbols, characters, images, terms,

numbers, or the like. It should be borne in mind, however, that all of these and similar terms are associated with the appropriate physical quantities, and that these terms are merely convenient labels applied to these physical quantities, individually or in groups.

This detailed description is presented largely in terms of flowcharts, display images, algorithms, and symbolic representations of operations of data bits within at least one computer readable medium, such as a memory. Indeed, such descriptions and representations are the type of convenient labels used by those skilled in programming and/or the data processing arts to effectively convey the substance of their work to others skilled in the art. A person skilled in the art of programming may use these descriptions to readily generate specific instructions for implementing a program according to embodiments of the invention.

Often, for the sake of convenience only, it is preferred to implement and describe a program as various interconnected distinct software modules or features, individually and collectively also known as software. This is not necessary, however, and there may be cases where modules are equivalently aggregated into a single program with unclear boundaries. In any event, the software modules or features of this description may be implemented by themselves, or in combination with others. Even though it is said that the program may be stored in a computer-readable medium, it should be clear to a person skilled in the art that it need not be a single memory, or even a single machine. Various portions, modules or features of it may reside in separate memories, or even separate machines. The separate machines may be connected directly, or through a network, such as a local access network (LAN), or a global network, such as the Internet.

It will be appreciated that some of these methods may include software steps that may be performed by different modules of an overall software architecture. For example, data forwarding in a router may be performed in a data plane, which consults a local routing table. Collection of performance data may also be performed in a data plane. The performance data may be processed in a control plane, which accordingly may update the local routing table, in addition to neighboring ones. A person skilled in the art will discern which step is best performed in which plane.

An economy is achieved in the present document in that a single set of flowcharts is used to describe both programs, and also methods. So, while flowcharts are described in terms of boxes, they can mean both method and programs.

For this description, the methods may be implemented by machine operations. In other words, embodiments of programs are made such that they perform methods in accordance to embodiments of the invention that are described in this document. These may be optionally performed in conjunction with one or more human operators performing some, but not all of them. As per the above, the users need not be collocated with each other, but each only with a machine that houses a portion of the program. Alternately, some of these machines may operate automatically, without users and/or independently from each other.

Example Methods

FIG. 5 shows a flowchart 500 for describing methods according to embodiments, for an external medical device to deliver electrical therapy to a patient. The method of flowchart 500 may also be practiced by external defibrillators made according to embodiments described above, such as defibrillator 300.

According to an operation 510, electrical energy is stored, such as in an energy storage module.

According to a next operation 530, it is determined whether defibrillation is advised for the patient.

According to a next operation 540, execution branches according to the outcome of operation 530. If defibrillation is not advised, execution can return to operation 530 as shown in the example of FIG. 5, or terminate.

According to a next operation 560, if defibrillation is indeed advised at operation 540, a defibrillation shock is delivered to the patient. As also per the above, the defibrillation shock can be delivered automatically or responsive to a user operating a user interface of the device.

According to a next operation 570, pacing pulses are delivered to the patient, such as shown in FIG. 4. Again as per the above, in some embodiments, the pacing pulses can be delivered without further analyzing an ECG of the patient, and/or without making any other preparation or needing to receive any input for operation 570 after operation 560.

According to an optional next operation 580, a future delivery of pacing pulses is adjusted. Operation 580 can be performed in a number of ways, and in a number of different contexts.

In one context, the therapy will be repeated, but with different parameters. For example, an adjustment can be made in how the inter-pulse time duration is determined, or the spacing of the pacing pulses, or their number or their amplitude.

Another context is when the defibrillation shock and one or more of the pacing pulses have been delivered to the patient as a test for gauging a patient's reaction. The test would be for preparing for a defibrillator precustomized to the patient, such as a wearable defibrillator or a defibrillator for use in a facility like a hospital or special care unit or a retirement home. It is possible that some patients may find that post-shock pacing may be arrhythmogenic, while others may find it to be anti-arrhythmic. If post-shock pacing is known to be harmful to a particular patient, then it may be desirable to configure the device to deliver a shock alone for that patient. Accordingly, the future delivery of the pacing pulses can be adjusted in any number of ways. In some embodiments, the pacing pulses may not be delivered at all. For patients that shouldn't receive pacing pulses, the determination would have to occur at 570, not at 580 where the pacing pulses are adjusted.

FIG. 6 shows a flowchart 600 for describing methods according to embodiments for an external medical device to deliver electrical therapy to a patient. The method of flowchart 600 may also be practiced by external defibrillators made according to embodiments described above, such as defibrillator 300. It will be recognized that a number of the operations of flowchart 600 are similar to those of flowchart 500.

According to an operation 610, electrical energy is stored in a battery of the device, for example when the device is initially prepared for use. According to a next operation 620, an ECG of the patient is analyzed.

According to a next operation 630, it is determined whether defibrillation is advised for the patient. Operation 630 can be performed as a result of the analysis of the ECG at operation 620.

According to a next operation 640, execution branches according to the outcome of operation 630. If defibrillation is not advised, execution can return to operation 630 as shown in the example of FIG. 6, or terminate.

According to a next operation 650, an inter-pulse time duration is determined from the ECG analysis of operation 620.

According to a next operation **660**, if defibrillation is indeed advised at operation **640**, a defibrillation shock is delivered to the patient. As also per the above, the defibrillation shock can be delivered automatically or responsive to a user operating a user interface of the device. For delivering a shock, the stored energy would be used to charge the capacitor. In most embodiments, the capacitor would be charged only after it has been determined that shock is advised.

According to an optional next operation **670**, pacing pulses are delivered to the patient. Two successive pacing pulses may have a spacing of the inter-pulse time duration. Again as per the above, in some embodiments, the pacing pulses can be delivered without further analyzing an ECG of the patient, and/or without making any other preparation or needing to receive any input for operation **670** after operation **660**.

According to an optional next operation **680**, a future delivery of pacing pulses is adjusted. Operation **680** can be performed similarly to previously described operation **580**.

For both flowcharts **500** and **600**, it will be recognized that a number of their operations can be augmented with what was described above.

In accordance with embodiments of the invention, the pacing is far different from the pacing therapy typically delivered from an external defibrillator/pacer. Typical anti-bradycardia pacing is done at a rate of 80-90 bpm, and is inhibited when an intrinsic complex is detected. In accordance with embodiments of the invention, the pacing is delivered after defibrillation shock **448**, at a higher rate, such as 300 bpm. In other words, the spacing between pulses **452**, **453** can be such that these two successive pacing pulses are delivered faster than an instantaneous rate of 200 bpm. Moreover, in accordance with embodiments of the invention, pacing pulses **452**, **453** are not inhibited by complexes detected in the ECG.

Pacing for anti-bradycardia is different. More particularly, ECG sensing is required, plus the determination of whether QRS complexes are present. If there is a period of time with no QRS complexes, the defibrillator delivers a pacing pulse. This requires ECG sensing electrodes that are separate from the therapy electrodes because the artifact created by the pacing pulse prohibits therapy and sensing from the same set of electrodes. There are currently no AEDs that are able to pace because AEDs have only one set of electrodes. In accordance with embodiments of the invention, the pacing, however, APSAT pacing could be delivered from an AED or a manual defibrillator, because it does not necessarily require a separate set of sensing electrodes.

Still on the topic of pacing for anti-bradycardia, the delivery of conventional anti-bradycardia pacing is also complicated because it is difficult to know whether the patient is conscious when the pacing pulses are delivered. If the patient is conscious, then steps must be taken to alleviate the pain. Typically, the current is set to the minimum level in order to achieve capture. Still, sedation may be necessary. Notes and Additional/Alternative Implementation Details

In the above description of exemplary implementations, for purposes of explanation, specific numbers, materials configurations, and other details are set forth in order to better explain the present invention, as claimed. However, it will be apparent to one skilled in the art that the claimed invention may be practiced using different details than the exemplary ones described herein. In other instances, well-known features are omitted or simplified to clarify the description of the exemplary implementations.

The inventor intends the described exemplary implementations to be primarily examples. The inventor does not intend these exemplary implementations to limit the scope of the appended claims. Rather, the inventor has contemplated that the claimed invention might also be embodied and implemented in other ways, in conjunction with other present or future technologies.

Moreover, the word “exemplary” is used herein to mean serving as an example, instance, or illustration. Any aspect or design described herein as exemplary is not necessarily to be construed as preferred or advantageous over other aspects or designs. Rather, use of the word “exemplary” is intended to present concepts and techniques in a concrete fashion. The term “technology,” for instance, may refer to one or more devices, apparatuses, systems, methods, articles of manufacture, and/or computer-readable instructions as indicated by the context described herein.

As used in this application, the term “or” is intended to mean an inclusive “or” rather than an exclusive “or.” That is, unless specified otherwise or clear from context, “X employs A or B” is intended to mean any of the natural inclusive permutations. That is, if X employs A; X employs B; or X employs both A and B, then “X employs A or B” is satisfied under any of the foregoing instances. In addition, the articles “a” and “an” as used in this application and the appended claims should generally be construed to mean “one or more,” unless specified otherwise or clear from context to be directed to a singular form.

Note that the order in which the processes are described is not intended to be construed as a limitation, and any number of the described process blocks can be combined in any order to implement the processes or an alternate process. Additionally, individual blocks may be deleted from the processes without departing from the spirit and scope of the subject matter described herein.

One or more embodiments described herein may be implemented fully or partially in software and/or firmware. This software and/or firmware may take the form of instructions contained in or on a non-transitory computer-readable storage medium. Those instructions may then be read and executed by one or more processors to enable performance of the operations described herein. The instructions may be in any suitable form, such as but not limited to source code, compiled code, interpreted code, executable code, static code, dynamic code, and the like. Such a computer-readable medium may include any tangible non-transitory medium for storing information in a form readable by one or more computers, such as but not limited to read only memory (ROM); random access memory (RAM); magnetic disk storage media; optical storage media; a flash memory, etc.

The term “computer-readable media” includes computer-storage media. For example, computer-storage media may include, but are not limited to, magnetic storage devices (e.g., hard disk, floppy disk, and magnetic strips), optical disks (e.g., compact disk [CD] and digital versatile disk [DVD]), smart cards, flash memory devices (e.g., thumb drive, stick, key drive, and SD cards), and volatile and nonvolatile memory (e.g., RAM and ROM).

In the claims appended herein, the inventor invokes 35 U.S.C. §112, paragraph 6 only when the words “means for” or “steps for” are used in the claim. If such words are not used in a claim, then the inventor does not intend for the claim to be construed to cover the corresponding structure, material, or acts described herein (and equivalents thereof) in accordance with 35 U.S.C. §112, paragraph 6.

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What is claimed is:

1. An external medical device which facilitates delivery of electrical energy to a patient, the external medical device comprising:

a housing external to the patient;

an energy storage module within the housing, the energy storage module configured to store electrical energy;

a processor configured to determine whether defibrillation is advised for the patient and, if so, the processor being further configured to control a delivery of the stored electrical energy to the patient, the delivery being controlled so that:

a first portion of the stored electrical energy is delivered as a defibrillation shock, and

a second portion of the stored electrical energy is delivered as an additional lead pacing pulse; and

a measurement circuit configured to measure an impedance of the patient while the defibrillation shock is delivered, the processor being further configured to adjust an amount of energy of the additional lead pacing pulse based on the measured impedance.

2. The device in accordance with claim 1, wherein the external medical device is one of a monitor-defibrillator, an AED and a wearable cardiac defibrillator.

3. The device in accordance with claim 1, wherein the first portion has an energy level of at least 50 J, and the second portion has an energy level of at most 5 J.

4. The device in accordance with claim 1, wherein the processor is further configured to control delivery of the additional lead pacing pulse within five seconds after the defibrillation shock is delivered.

5. The device in accordance with claim 1, wherein the processor is further configured to control delivery of the lead pacing pulse without further analyzing an ECG of the patient in a time interval between when the defibrillation shock is delivered and when the lead pacing pulse is delivered.

6. The device in accordance with claim 1, wherein the processor is further configured to automatically control delivery of the stored electrical energy if the processor determines that defibrillation is advised for the patient.

7. The device in accordance with claim 1, further comprising a user interface, wherein the processor is further configured to deliver the stored electrical energy in response to an input received at the user interface.

8. The device in accordance with claim 1, wherein the processor is further configured to control delivery of a third portion of the stored electrical energy as at least six more pacing pulses after the lead pacing pulse, each of the six more pacing pulses having an energy level of no more than 5 J.

9. The device in accordance with claim 1, wherein the energy storage module includes a capacitor charged to deliver the additional pacing pulse.

10. The device in accordance with claim 1, wherein the processor is further configured to, after the pacing pulse has been delivered, again determine whether defibrillation is advised, and, if so, to deliver a second defibrillation shock not followed by a lead pacing pulse, the processor further being configured to dynamically adjust an amount of energy of the second defibrillation shock based on the measured impedance.

11. An article comprising: a storage medium, the storage medium having instructions stored thereon, wherein when the instructions are executed by at least one medical device configured to deliver electrical energy to a patient, they result in:

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storing electrical energy;

determining whether defibrillation is advised for the patient; and, if so:

delivering to the patient externally:

a first portion of the stored electrical energy as a defibrillation shock, and

a second portion of the stored electrical energy as an additional lead pacing pulse;

measuring an impedance of the patient while the defibrillation shock is delivered; and

adjusting an amount of energy-of the additional lead pacing pulse based on the measured impedance.

12. A method which facilitates delivery of electrical energy to a patient by an external medical device, the method comprising:

storing electrical energy;

determining whether defibrillation is advised for the patient; and, if so:

delivering to the patient externally:

a first portion of the stored electrical energy as a defibrillation shock, and

a second portion of the stored electrical energy as an additional lead pacing pulse;

measuring an impedance of the patient while the defibrillation shock is delivered; and

adjusting an amount of energy of the additional lead pacing pulse based on the measured impedance.

13. The method in accordance with claim 12, wherein the first portion has an energy level of at least 50 J, and the second portion has an energy level of at most 5 J.

14. The method in accordance with claim 12, wherein delivering to the patient externally a second portion of the stored electrical energy as an additional lead pacing pulse comprises delivering to the patient externally a second portion of the stored electrical energy as an additional lead pacing pulse within five seconds after delivering the defibrillation shock.

15. The method in accordance with claim 12, further comprising receiving an adjustment input based on a gauged reaction of the patient to the defibrillation shock and the lead pacing pulse, and adjusting the external medical device in response to the adjustment input.

16. The method in accordance with claim 12, wherein delivering to the patient externally a second portion of the stored electrical energy as an additional lead pacing pulse comprises delivering to the patient externally a second portion of the stored electrical energy as an additional lead pacing pulse without further analyzing an ECG of the patient in a time interval between delivering the defibrillation shock and delivering the lead pacing pulse.

17. The method in accordance with claim 12, wherein the delivering to the patient is automatic in response to determining that defibrillation is advised for the patient, the method further comprising dynamically adjusting an amount of energy of the defibrillation shock based upon the measured impedance.

18. The method in accordance with claim 12, further comprising receiving a user input at a user interface of the device, wherein the delivered energy is delivered in response to the user input.

19. The method in accordance with claim 12, wherein delivering to the patient externally a second portion of the stored electrical energy as an additional lead pacing pulse comprises delivering to the patient externally a second portion of the stored electrical energy as at least six more

pacing pulses after the lead pacing pulse, each of the six more pacing pulses having an energy level of no more than 5 J.

20. The method in accordance with claim 12, further comprising, after the pacing pulse has been delivered, the processor again determining whether defibrillation is advised, and, if so, delivering a second defibrillation shock having an energy level of at least 50 J, the second defibrillation shock not followed by a lead pacing pulse.

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